Crop Protection 29 (2010) 239–248

Contents lists available at ScienceDirect

Crop Protection

journal homepage: www.elsevier.com/locate/cropro

Variable rate dosing in precision viticulture: Use of electronic devices to improve application efficiency

J. Llorens [a], E. Gil [a,*], J. Llop [a], A. Escolà [b]

[a] Dept. Agri Food Engineering and Biotechnology, Universitat Politècnica de Catalunya, Parc Mediterrani de la Tecnologia, Campus del Baix Llobregat UPC, Edifici ESAB – Avda. Canal Olímpic, 15, 08860 Castelldefels (Barcelona), Spain

[b] Dept. Agro Forestry Engineering, Universitat de Lleida, Escola Tècnica Superior d'Enginyeria Agrària, Av. Rovira Roure 191, 25198 Lleida, Spain

ARTICLE INFO

Article history:
Received 3 April 2009
Received in revised form
16 December 2009
Accepted 16 December 2009

Keywords:
Ultrasonic sensor
Vineyard
Canopy volume
Variable rate application
Precision viticulture
Crop-adapted spraying
Vine row volume (VRV)

ABSTRACT

Two different spray application methods were compared in three vine varieties at different crop stages. A conventional spray application with a constant volume rate per unit ground area (l ha^{-1}) was compared with a variable rate application method designed to compensate electronically for measured variations in canopy dimensions. An air-blast sprayer with individual multi-nozzle spouts was fitted with three ultrasonic sensors and three electro valves on one side, in order to modify the emitted flow rate of the nozzles according to the variability of canopy dimensions in real time. The purpose of this prototype was to precisely apply the required amount of spray liquid and avoid over dosing. On average, a 58% saving in application volume was achieved with the variable rate method, obtaining similar or even better leaf deposits.

1. Introduction

The efficiency of plant protection products (PPP) depends on many interacting factors. Crop characteristics (canopy structure, vegetative stage, variety, etc.), application technique, weather conditions, applied dose rate and others are interdependent factors that allow, in an adequate combination, to achieve high efficacy and efficiency values.

Crop-adapted dosing of agrochemicals has been widely discussed in many publications (Furness, 2003; Walklate et al., 2003; Gil et al., 2005; Godyn et al., 2005; Viret et al., 2005; Pergher and Petris, 2008). In all cases the main goal has been to adapt the total amount of PPP to crop characteristics but difficulties were encountered in the selection of the most suitable crop parameters. The high degree of variability in crop characteristics has increased the difficulty in obtaining general solutions well adapted to all crops and situations.

The use of orchard canopy volume as a basis for chemical application rate calculation and system design was discussed and tested by Sutton and Unrath (1984, 1988). The tree row volume concept maintains that chemical rate recommendation and application should be based upon crop canopy volume rather than on land area. Following this methodology other trials have been conducted in order to adapt the spray volume to crop dimensions in vineyards (Siegfried et al., 2007; Pergher and Petris, 2008). In all cases, accurate measurements of crop dimensions are a key factor for final success. The use of electronic devices to measure crop dimensions is not a new idea. McConnell et al. (1983) proposed the use of a system with a vertical mast with range transducers to measure tree extension, from the trunk outward and towards the row middle. More recently, Giles et al. (1989), using a modified orchard air-blast sprayer equipped with three ultrasonic transducers, concluded that savings in pesticide application when using the electronic control system was strongly related to target crop architecture. The same authors concluded that sprayer control based upon target measurement, rather than simple target detection resulted in substantial increases in savings of applied spray liquid.

To solve the difficulties encountered in crop characterization and to accomplish the recent EU aim to reduce the total amount of PPP (COM, 2009), environmentally-safe spraying techniques have been developed to spray only when and where needed with reduced losses to the environment (Doruchowski and Holownicki, 2000). Recent advances in computer hardware and software, global navigation satellite systems (GNSS), canopy sensors and remote

* Corresponding author. Tel.: +34 935 521 099; fax: +34 935 521 121.
E-mail address: emilio.gil@upc.edu (E. Gil).

0261-2194/$ – see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.cropro.2009.12.022

sensing offer opportunities for fast and inexpensive measurements of tree canopy characteristics for variable rate technologies (Zaman and Salyani, 2004). Walklate et al. (2006) using a LIDAR (LIght Detection and Ranging) concluded that area density and height adjustments were the best crop structure parameters on which a simplified scheme for pome fruit spraying could be based on. Rosell et al. (2009) developed a LIDAR-based measurement system for the estimation of physical and structural characteristics of plants (plant volume, leaf area density and leaf area index). The different shapes, sizes and foliar densities found in tree crops during the same growing season, require a continuous adjustment of the applied dose rate to optimize the spray application efficiency and to reduce environmental contamination (Solanelles et al., 2002). Crop characteristics are directly related to the total amounts of deposit on leaves and values of leaf area and canopy dimensions (mainly height and width) can widely affect the efficiency values, as a relationship between the expected deposit and the actual one (Gil et al., 2005).

Target detection has been developed either by using advanced techniques, such as vision systems and laser scanning, or by ultrasonic and spectral systems. Gil et al. (2007) obtained a significant reduction in the total amount of applied volume (57%) using a sprayer prototype with ultrasonic sensors able to measure the crop width variations and to apply a variable dose rate according to the instantaneous measured vine row volume (VRV), in comparison with a conventional and constant application volume rate. However, this reduction did not affect the results in terms of deposit, leaf coverage and penetration where similar normalized values were achieved.

Whitney et al. (2002) investigated the ultrasonic transducer's response to different parts of a citrus canopy and also examined the effect of the sampling frequency and the transducer spacing on canopy volume determination. More recently Balsari et al. (2008) using a crop identification system based on ultrasonic sensors, confirmed its suitability for detecting canopy characteristics in real time, independently of the forward speed, as previous studies already indicated (Zaman and Salyani, 2004).

It seems that any approach to adapt the spraying volume rate to crop characteristics will lead with a general principle that foliar application must results in similar deposits (μg cm^{-2}), independently of crop size or canopy density. That system would avoid the problem of over dosage of PPP detected as a frequent problem in the early crop growth stages, especially in orchards and vineyards where in most cases pesticide dose rate is expressed in many different ways (Koch, 2007).

But in any case selective application with a precise target detection system must assure uniform deposits and must guarantee that large savings in sprayed application volume rates will not affect biological efficacy. This assumption has been confirmed in trials using different electronic control strategies (Koch and Weisser, 2000) who obtained no significant differences between a sensor based and a conventional application technique for apple scab (Ventura inequalis), pear psylla (*Cacopsylla pyri xx*) and leaf and bud mite (*Aculus schechtendali xx*) control.

This paper describes the characteristics of a sprayer prototype able to automatically adapt the spray application rate according to the target geometry, using an adapted tree row volume (TRV) estimation method (Pergher and Petris, 2008; Rüegg et al., 1999). Results in terms of deposit of tracer (μg cm^{-2}) and leaf recovery (actual recovered tracer compared with the expected according leaf area) have been calculated and compared with those obtained with a conventional method based on a per land surface dosage system (l ha^{-1}). In order to evaluate the influence of the leaf morphology, research trials have been conducted in three representative vineyards (*cv. Merlot*, *cv. Cabernet Sauvignon* and *cv. Tempranillo*) at two growth stages.

The objectives of this research were: a) to analyze the ability of ultrasonic sensors in determining vineyard structure; b) to investigate the spray volume savings achieved through the use of a target measurement sprayer control system based on the instantaneous vine volume, *iVV* (an adapted VRV principle); to evaluate the efficiency of the proposed spraying system, in comparison with the conventional application based on land surface; and d) to determine the relationship between spray volume savings and canopy structure.

2. Material and methods

2.1. Sprayer design

The development and testing of the target measurement and sprayer control system used in this research have been previously described and discussed (Gil et al., 2007) and will only be briefly outlined in this article. The measurement system and the electronic process unit were mounted on an air-blast orchard sprayer (Hardi LE-600 BK/2 with a centrifugal fan of 400 mm diameter). The sprayer was equipped with six individual and adjustable spouts (three on each side of the machine) in which up to five nozzles could be arranged on each one. A mast was fitted on its left side to hold three ultrasonic sensors and a solenoid high frequency electro

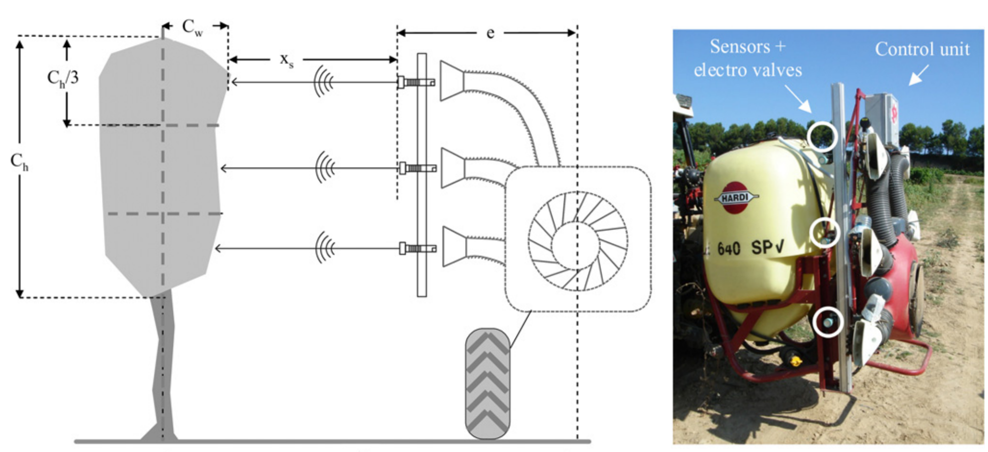

Fig. 1. Principle of functioning of the prototype (left) and prototype with electronic devices (right).